# SECOND QUARTERLY REPORT

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# BONDING LARGE AREA SILICON WAFERS



CONTRACT NO. 952022

PREPARED FOR

JET PROPULSION LABORATORY
4800 Oak Grove Drive
Pasadena, California 91103



PREPARED BY

MOTOROLA, INC.
SEMICONDUCTOR PRODUCTS DIVISION
5005 E. McDowell Road
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# ABSTRACT

Results are reported of the second 3 months study of an 18-month program for the development of techniques for bonding large area silicon single crystals to heat sinks. A method is described for preparing flat and parallel surfaces for large silicon wafers to reduce mechanical stress and to provide a known heat path. Aluminum-germanium eutectic solder has been successfully used to bond silicon to thick aluminum films deposited on Kovar alloy bases. The method used is not suitable for production, however, and a technique must be developed to eliminate effects attributed to the presence of silicon dioxide and aluminum oxide. Instruments available for measuring thermal and mechanical properties of solder alloys are briefly described and basic equations are generated for thermal conduction analysis and stress analysis.

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## LIST OF ILLUSTRATIONS

## 1.0 INTRODUCTION

This report describes work performed during the second 3-month period of an 18-month program on the development of techniques for reliably bonding large area silicon single crystals to suitable heat sinks. The purpose is to enable bonding of silicon single crystals greater than 10,000 square mils and approaching 2 inches in diameter to excellent heat sinks in a manner which does not damage the silicon or alter the electrical properties of semiconductor devices constructed therein. The system which should not degrade under repeated thermal shock is to be applied to the packaging of large scale integrated circuit devices.

Phase one of this program is a study of the basic properties of potential bonding materials and the development of analytical techniques which will determine the materials and processes to be evaluated on early large area bonding experiments.

Aluminum-germanium eutectic solder has been used to bond silicon to aluminum films deposited over Kovar. Techniques must be generated to eliminate the effects of (or the formation of) oxides on the silicon and aluminum surfaces which seriously interfere with wetting of the solder.

Samples of gold-silicon and gold-germanium eutectic solders have been ordered to enable a determination of their mechanical and thermal properties.

A method is described for producing flat and parallel surfaces on large area silicon wafers to reduce mechanical stress which may arise due to surface roughness and to provide a known heat path.

Instruments for determining the thermal and mechanical properties of materials are briefly described.

The basic equations for analysis of thermal conduction and stresses due to thermal expansion mismatch are developed and are currently being programmed for machine solution.

## 2.0 TECHNICAL DISCUSSION

### 2.1 ALUMINUM-GERMANIUM ALLOY SOLDER

One potentially promising solder alloy for bonding large area silicon wafers to stress relieving members is the near-eutectic composition alloy of aluminum and germanium. A phase diagram of this system as given by Hansen[(1)] is shown in Figure 1. As indicated, the eutectic composition melts at 424°C and contains 30 atomic percent (55 weight percent) germanium. This temperature is quite compatible with silicon devices and promises to possess a fair thermal conductivity.

The solid solubility curve of germanium into silicon shows 2.8 atom (7.2 weight) percent at 424°C falling off to 0.2 atomic (0.5 weight) percent at 294°C. This alloy should therefore make an excellent thermal and mechanical bond to aluminum at its meling point due to this solubility.

The literature also indicates a slight solubility of aluminum into molybdenum which would assist the bonding of that interface.

Efforts during this period were directed toward a study of bonding silicon dice to 4-micron-thick pads of aluminum vacuum deposited onto Kovar alloy. The silicon wafers were prepared, as

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(1) Max Hansen, Constitution of Binary Alloys, Second Edition, McGraw Hill, New York, 1958.

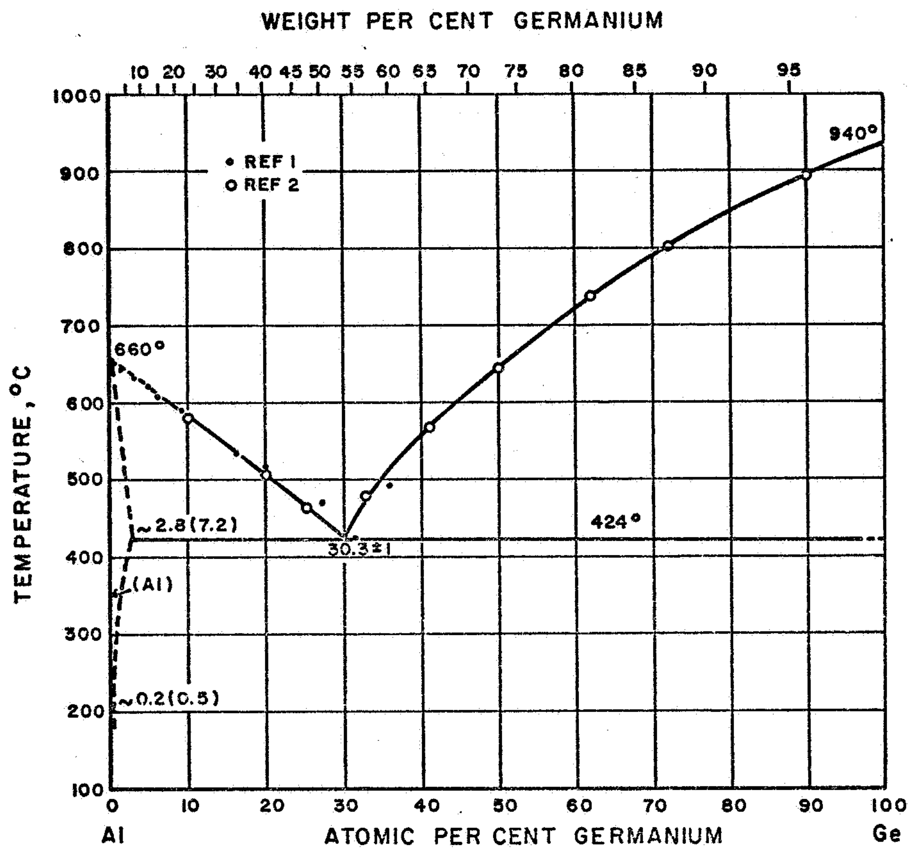



Figure 1. Al-Ge Phase Diagram

described in the previous report, by the evaporation of 1.5-micron-thick layers of aluminum and germanium onto the back side of the silicon.

As shown in the micrograph of Figure 2, difficulties were experienced at times in obtaining a sound joint. This is attributed to a layer of either aluminum oxide or silicon dioxide which interferes with the solder flow.

A micrograph of a sound joint is presented in Figure 3 which was prepared by first clamping the members together and then mechanically moving the die over the aluminized Kovar surface while hot to move away the interfering oxide. Although the bond appears good by microscopic inspection, this technique will not be an acceptable solution for production.

As stated previously, one source of the oxide which interferes with bonding could be silicon dioxide which forms over the freshly etched silicon prior to entering the vacuum system to receive the aluminum and germanium layers. Between 20 and 30 angstrom units of oxide can form at room temperature in the rinsing operation after etch and at a brief room ambient storage. Ohmic contact and bonding to silicon may be obtained by reduction of this thin layer of silicon dioxide by the reactive aluminum at elevated temperatures.

Motorola has recently determined the equation relating the rate of penetration of aluminum into silicon dioxide as a function of temperature to be

$$R = 6.0 \times 10^{19} \exp -(2.448/kT)$$

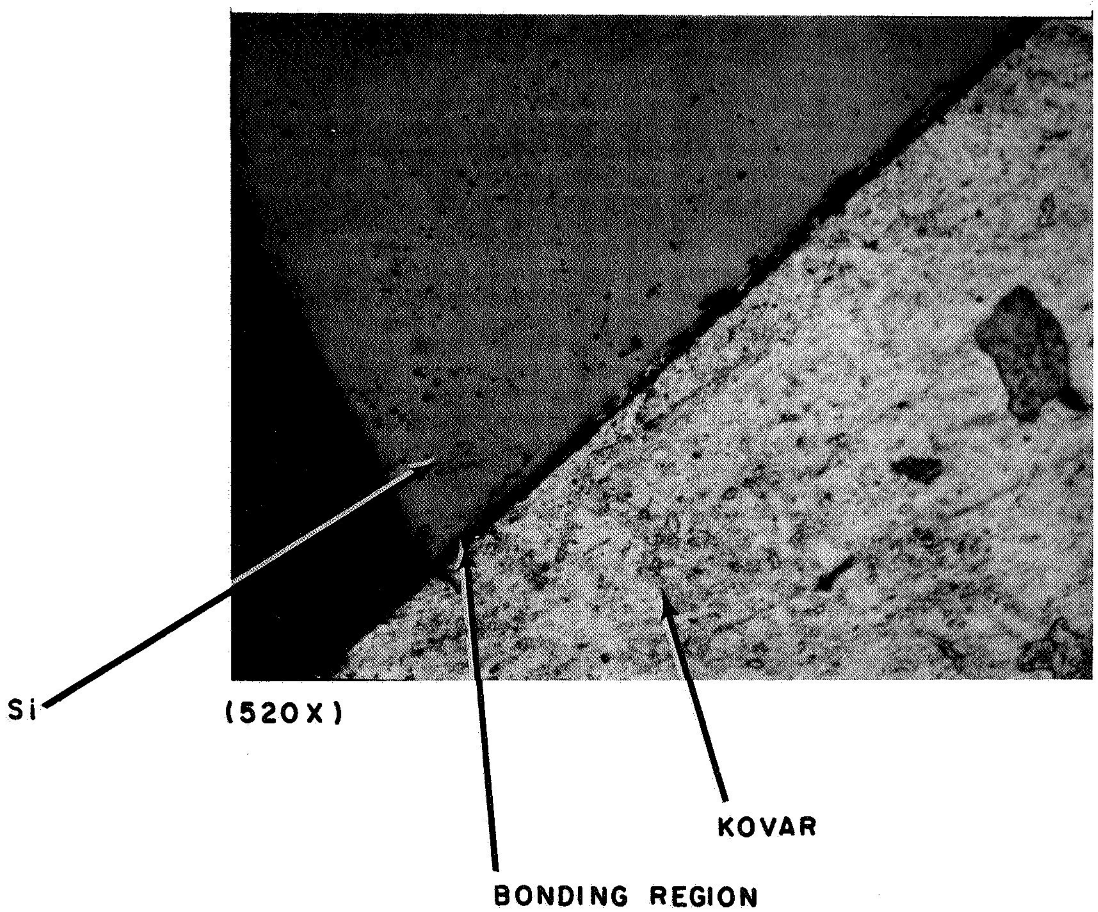



Figure 2. Photomicrograph of Silicon Bonded to Kovar by Al-Ge Solder (Poor Bond)

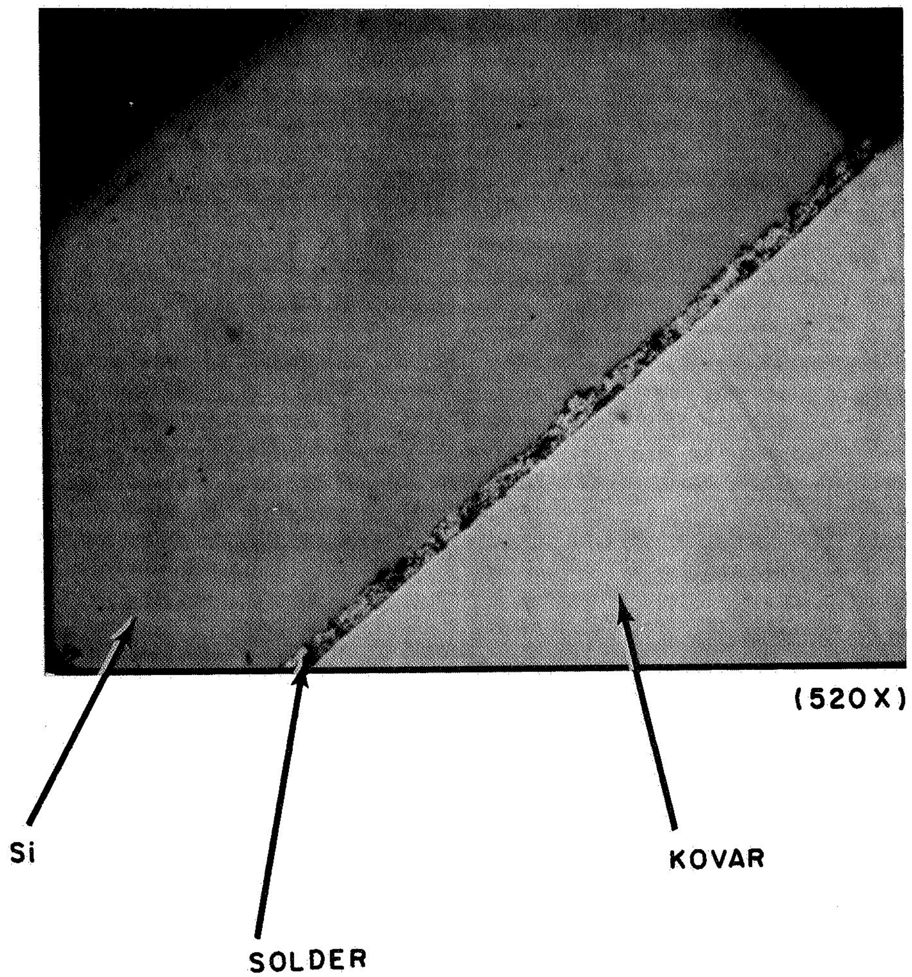



Figure 3. Photomicrograph of Section Through Silicon Bonded to Kovar by Al-Ge Solder (Good Bond)

where R is the penetration rate expressed in angstrom units per minute. At 545°C this rate is 50 angstroms per minute, at 510°C the rate reduces to 10 angstroms per minute, while at 460°C the rate is only 1 angstrom per minute.

It appears, then, in order to react through 30 angstroms of silicon dioxide, the initial evaporated aluminum layer should be baked within the vacuum system at 533°C for 1 minute or at 510°C for 3 minutes prior to being cooled to near room temperature before receiving the germanium layer.

The oxide layer on molybdenum, tungsten or Kovar should be removable chemically. We will explore bonding directly to the Mo, W, or Kovar done under dry nitrogen to prevent further oxide growth and interference at this interface. An aluminum layer on the heat sink, however, is still a problem in that it is immediately coated with oxide whenever exposed to air.

An aluminum electroplating technique involving a zincating or tinning process will be explored to deposit a nonreadily oxidizing metal over chemically cleaned aluminum. In the zincating or tinning process, aluminum surfaces are treated in a solution of alkali and zinc or tin ions. The alkali removes any oxide layer on the aluminum. Immediately after the bare aluminum is exposed to the solution, an electrolytic replacement reaction takes place whereby the zinc or tin ion plates onto the aluminum metal forming a protective thin layer preventing the further formation of aluminum oxide. The zinc or tin may then be electroplated by a more refractory metal such as copper or nickel to which the Al-Ge braze could be made in a protective gas ambient.

## 2.2 GOLD-SILICON AND GOLD-GERMANIUM SOLDERS

Both gold-silicon and gold-germanium eutectic solders are commonly used for bonding semiconductor devices to headers. The gold-germanium eutectic melts at 356°C at a composition of 27 atomic (12 weight) percent Ge while the gold-silicon eutectic melts at 370°C and has a composition 31 atomic (6 weight) percent silicon. There is only a slight solubility of Ge into Si, otherwise both systems form a continuous eutectic type alloy.

Very little information has been found in the literature on the thermal conductivities of these alloys. It is anticipated that the germanium-gold alloy should be preferred over the silicon-gold alloy from the viewpoint of thermal conductivity due to the smaller volume of the non-gold phase present. The slight solid solubility of germanium into gold, however, may offset this advantage.

Accordingly, samples of these alloys have been ordered from the Western Gold and Platinum Company for the determination of the thermal conductivity and the mechanical properties of these materials. These alloys in their sheet form will be acquired to be evaluated in solder forms.

## 2.3 BONDING SURFACE PREPARATION

Irregularities in flatness of surfaces to be bonded will introduce mechanical stress in the parts after they are bonded. To reduce these to a minimum and to control the wafer thickness and the parallelism of the large surfaces of silicon wafers, effort has been devoted to improve wafer polishing and lapping techniques.

The method for achieving flat and parallel surfaces and for controlling wafer thickness is as follows: The silicon is first sawed to a thickness of 17 $\pm$ 0.5 mils and then etched to a thickness of 15 $\pm$ 0.5 mils to remove saw damage.

The silicon slices are then cleaned and mounted on clean lapping carriers which have been stress relieved prior to being ground flat to $\pm$ 0.0005 inch on a surface grinder. The wafers are mounted by first heating the carriers and then spreading a thin layer of wax over the flat surface. The wafers are pressed into the molten wax and kept under pressure while the carrier cools and the wax sets.

The wafers are then lapped a few minutes until they all have a flattened surface after which they are removed, cleaned and again attached to the lap with the previously flattened surfaces adjacent to the lapping tool. Diamond stops set into the carriers stop the lapping at a wafer thickness of 12.5 $\pm$ 0.05 mils.

It is necessary to have carefully calibrated gauges and an optical flat to serve as an absolute reference. The lapping machine carriers and the lapping surface must be maintained flat. The carriers are surfaced by a Blanchard grinder while the lapping surface is maintained flat by large metal rings which continually circulate over the surface.

This technique has been used for preparing silicon wafers but is also applicable for preparing tungsten or molybdenum stress relieving members.

## 2.4 THERMOCONDUCTIVITY DETERMINATION

The Colora Messtecknik G.m.b.H of Germany thermal conductometer, which was discussed in the previous report, has arrived and currently is in the process of being installed. A view of this instrument is presented in Figure 4. It is capable of determining to within ±3 percent the thermal conductivity of solder alloys and other potentially important package materials. It should also provide a measurement of the thermal conductivity of various interfaces bonded by solders.

## 2.5 MECHANICAL PROPERTIES OF SOLDERS

An Instron Model TT Universal Testing Instrument, shown in Figure 5, will be used to measure the mechanical properties of candidate solder alloys. The Young's Modulus, elastic limit and sheer modulus of these alloys can be determined over a temperature range of -100° to +600°F through the use of an environmental chamber which surrounds the sample. A Custom Scientific Instrument dilatometer is also available for determining the thermal expansion coefficient of solder alloys. With this information combined with the results of the analysis of stresses built up between two members due to differences in expansion coefficients, it will be possible to determine whether or not the elastic limit of the solder will be exceeded for a given solder thickness and sample diameter.

## 2.6 HEAT CONDUCTION ANALYSIS

For many purposes on this study, a linear approach can be made to the analysis of thermal flow down a cylindrical structure from its point of generation to a sink. In the practical case, however, where the sources of heat (dissipating junctions and resistors) are not uniformly dispersed over the silicon, it becomes most important to calculate the effect this has on the junction temperature.

In the First Quarterly Progress Report, an analysis of thermal conduction for programming on a GE415 time sharing computer

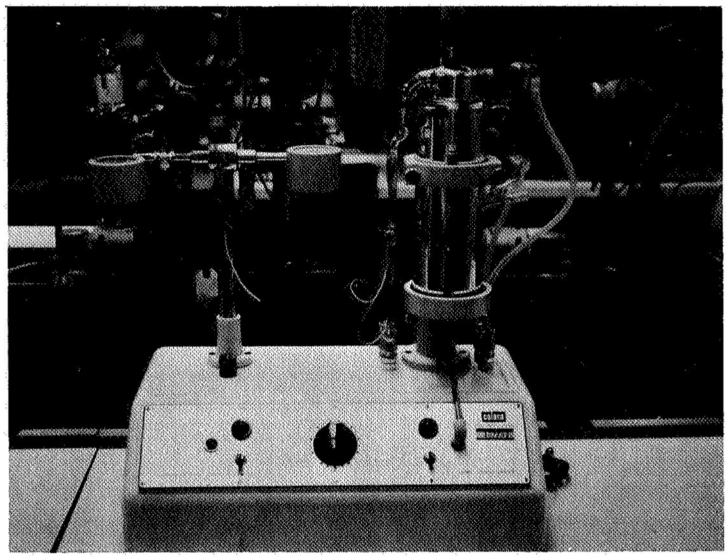


Figure 4. Colora Thermal Conductometer

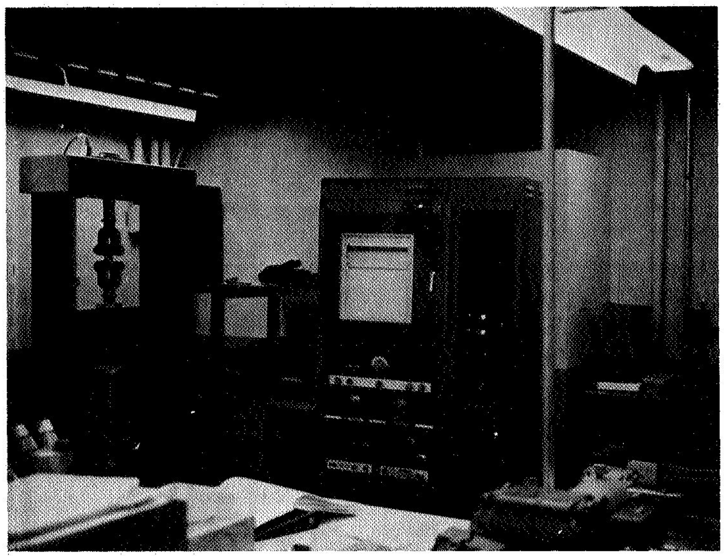


Figure 5. View of Model TT Instron Tester

was briefly presented. The general equation to be solved in dimensionless form was assumed to be the Fourier heat conduction equation. In this section, the Fourier equation is developed to establish an improved physical understanding of it. It is based upon the divergence of energy or an energy balance equation (equation of continuity)

$$\text{Energy accumulated} = \text{Energy generated} + \text{Energy flowing in} - \text{Energy flowing out.}$$

Assuming axial symmetry the elemental volume is shown in Figure 6. By inspection of Figure 7 where Q = Energy or Heat Flux in BTU/ft$^2$ sec it is seen that

$$\text{Energy in} = Q_r\ (r\ d\theta\ dz) + Q_z\ (r\ d\theta\ dr)$$

$$\text{Energy out} = (Q_r + \frac{\partial Q_r}{\partial r}\ dr)\ (r + dr)\ d\theta\ dz + (Q_z + \frac{\partial Q_z}{\partial z}\ dz)\ r\ d\theta\ dr$$

The energy accumulated in the incremental volume dV can be expressed as:

$$\text{Energy accumulated} = \frac{\partial E}{\partial t}\ dV$$

where E is energy expressed as BTU and t is time in seconds. Also, the energy generated can be expressed as

$$\text{Energy Generated} = W\ dV$$

where W is expressed as BTU/ft$^3$.

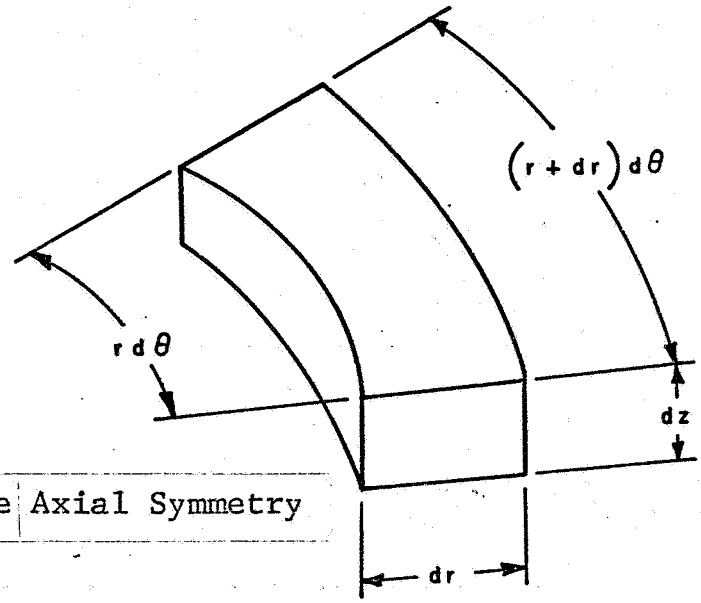



Figure 6. Elemental Volume Axial Symmetry

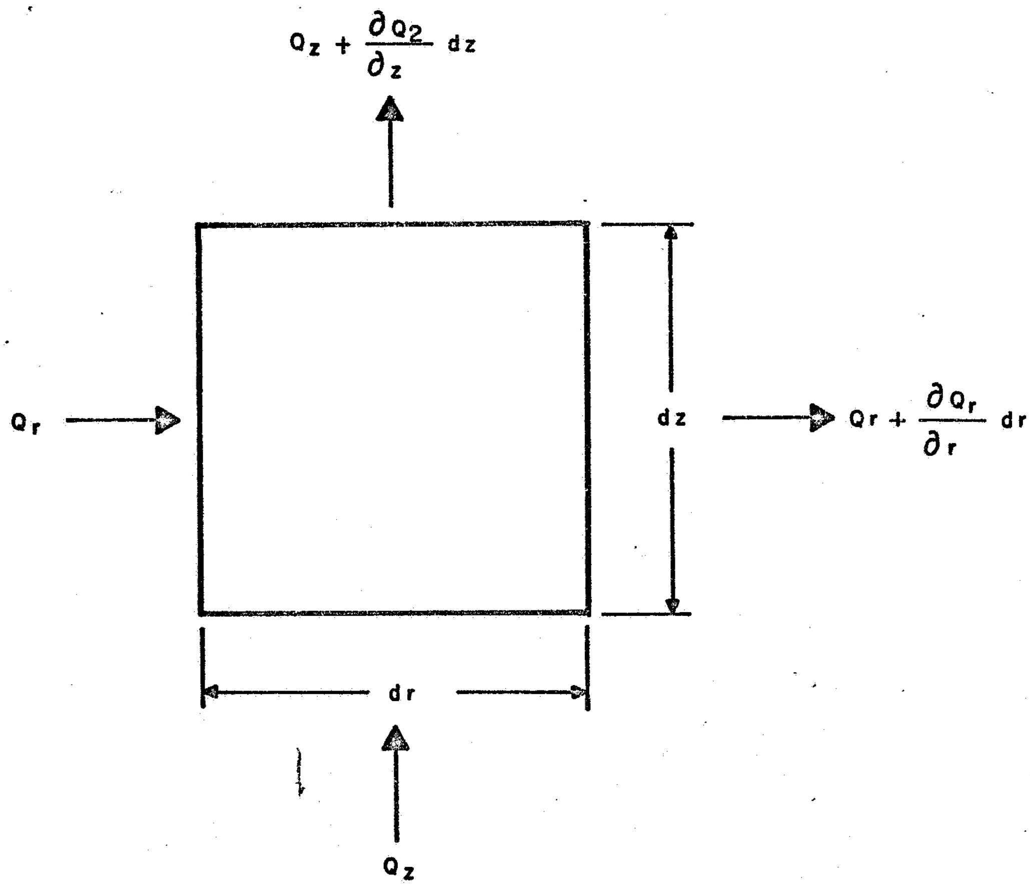



Figure 7. Heat Flux Notation

Substituting the above equivalents into the energy balance equation, the following equation results:

$$\frac{\partial E}{\partial t} dV = W\ dV - (Q_r + \frac{\partial Q_r}{\partial r})\ (r + dr)\ d\theta\ dz$$

$$- (Q_z + \frac{\partial Q_z}{\partial z} dz)\ r\ d\theta\ dr$$

$$+ Q_r\ r\ d\theta\ dz + Q_z\ r\ d\theta\ dr$$

or

$$\frac{\partial E}{\partial t} dV = W\ dV - Q_r\ dr\ d\theta\ dz - \frac{\partial Q_r}{\partial r}\ (r + dr)\ dr\ d\theta\ dz$$

$$- \frac{\partial Q_z}{\partial z}\ r\ dr\ d\theta\ dz$$

But $dV = r\ dr\ d\theta\ dz$

Dividing by $dV$ and assuming that $r + dr \approx r$

results in the following:

$$\frac{\partial E}{\partial t} = W - \frac{1}{r} Q_r - \frac{\partial Q_r}{\partial r} - \frac{\partial Q_z}{\partial z}$$

The heat flux terms are defined as

$$Q_z = - k \frac{\partial T}{\partial z}; \quad Q_r = - k \frac{\partial T}{\partial r}$$

The total energy of the system referenced to some temperature $T = 0$ is

$$E = \rho\ C_p\ T$$

where $\rho$ is density in $lbs/ft^3$

$C_p$ is heat capacity in BTU/lb°F

T = temperature in °F.

Assuming constant $\rho$, $C_p$ and k, the energy balance becomes

$$\rho\ C_p \frac{\partial T}{\partial t} = k\ (\frac{1}{r}\frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial r^2} + \frac{\partial^2 T}{\partial z^2}) + W$$

Dividing each side of this equation by $\rho\ C_p$

$$\frac{\partial T}{\partial t} = \frac{k}{\rho C_p}\ (\frac{1}{r}\frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial r^2} + \frac{\partial^2 T}{\partial z^2}) + \frac{W}{\rho C_p}$$ [2]

The above equation can be handled easier by writing it in a semidimensionless form with the substitutes

$t' = k\ t/C_p\ \rho R^2$

$r' = r/R$

$z' = z/R$

$T = T$ (dimension is degrees)

$W' = R^2 W/k$ (dimension is degrees)

[2] This is the same equation as presented by Benet and Myers, Momentum, Heat, and Mass Transfer, pp 242-252, McGraw Hill, 1962, New York with the addition of the generation term and less the angular term which is considered here to be zero.

Where R is the radius of the cylinder in feet. Since nothing was to be gained by placing temperature in a dimensionless form, this was left in degrees. The following equation results:

$$\frac{\partial T}{\partial t'} = \frac{1}{r'}\frac{\partial T}{\partial r'} + \frac{\partial^2 T}{\partial r'^2} + \frac{\partial^2 T}{\partial z'^2} + W'$$

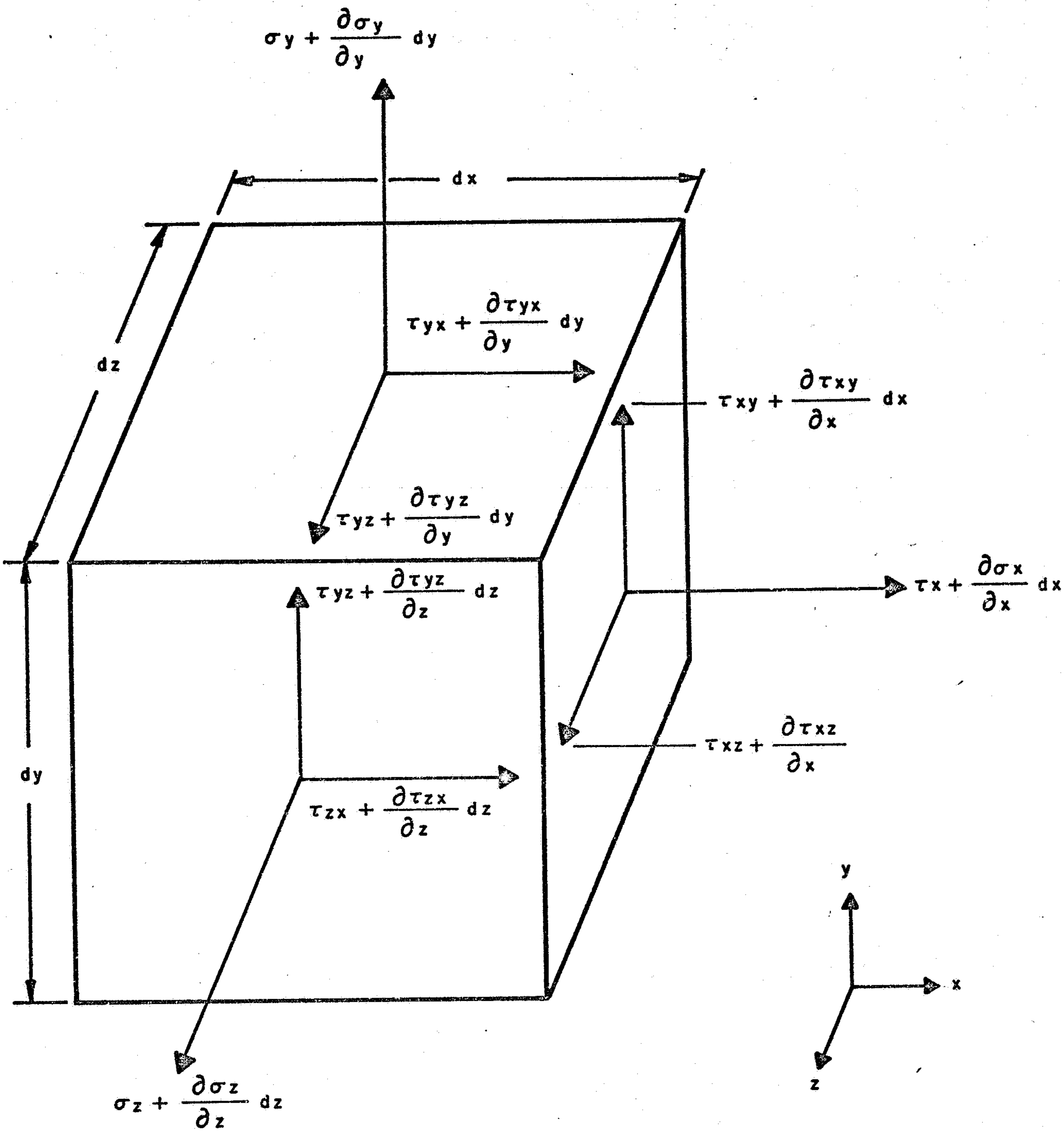
Dropping the primes, the equation is presented as

$$\frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial r^2} + \frac{\partial^2 T}{\partial z^2} + W$$

## 2.7 STRESS ANALYSIS

It is desirable to calculate the stress which is generated between joined members due to the disparity between their thermal expansion coefficients. From this knowledge, the required mechanical properties of solders and the desired solder thickness can be determined which will result in a mechanically sound system since this is essentially the sole source of mechanical stress applied to the bond. In a previous section an Instron Tester is described which is to be used for evaluating the Young's modulus, sheer modulus and the elastic limit of metal and potential solder alloys. In this section the basic equations for stress analysis are derived. These currently are being prepared for solution on a GE415 time sharing computer.

The basic equations in stress analysis are the equilibrium equations that are derived from a force balance. The force balance presented here is in rectangular coordinates with no body forces. Figure 8 shows a diagram of a unit cell with the sheer and tensile forces shown.




Note: The forces on the faces not shown are identical to those given minus the partial term.

Figure 8. Force Balance Notation

To maintain equilibrium, the sum of the forces in each coordinate direction must be zero. Summing the forces in the x direction:

$$\Sigma F_x = 0 = (\sigma_x + \frac{\partial\sigma_x}{\partial x} dx)\ dy\ dz + (\tau_{zx} + \frac{\partial\tau_{zx}}{\partial z} dz)\ dx\ dy$$

$$+ (\tau_{yx} + \frac{\partial\tau_{yx}}{\partial y} dy)\ dx\ dz - \sigma_x\ dy\ dz - \tau_{zx}\ dz\ dy$$

$$- \tau_{yx}\ dx\ dy$$

$$= \frac{\partial\sigma_x}{\partial x} dx\ dy\ dz + \frac{\partial\tau_{zx}}{\partial z} dx\ dy\ dz + \frac{\partial\tau_{yx}}{\partial y} dx\ dy\ dz$$

dividing by the volume element dx dy dz

$$\Sigma F_x = \frac{\partial\sigma_x}{\partial x} + \frac{\partial\tau_{yx}}{\partial y} + \frac{\partial\tau_{zx}}{\partial z} = 0$$

Summing the forces in the other two directions in a similar manner

$$\Sigma F_y = \frac{\partial\tau_{xy}}{\partial x} + \frac{\partial\sigma_y}{\partial y} + \frac{\partial\tau_{zx}}{\partial z} = 0$$

$$\Sigma F_z = \frac{\partial\tau_{xz}}{\partial x} + \frac{\partial\tau_{yx}}{\partial y} + \frac{\partial\sigma_z}{\partial z} = 0$$

The above three equations must be satisfied for a force equilibrium to be maintained.

Equations relating strains to stresses when a temperature step, T, is applied are given by Boresi[(3)] as:

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[(3)] Boresi, Elasticity in Engineering Mechanics, Prentice Hall, Inc., New Jersey, 1965, page 225.

$$\epsilon_x = \frac{1}{E}[\sigma_x - \nu(\sigma_y + \sigma_z)] + kT$$

$$\epsilon_y = \frac{1}{E}[\sigma_y - \nu(\sigma_x + \sigma_z)] + kT$$

$$\epsilon_z = \frac{1}{E}[\sigma_z - \nu(\sigma_x + \sigma_y)] + kT$$

$$\gamma_{xy} = \frac{2(1+\nu)}{E} \tau_{xy}$$

$$\gamma_{xz} = \frac{2(1+\nu)}{E} \tau_{xz}$$

$$\gamma_{yz} = \frac{2(1+\nu)}{E} \tau_{yz}$$

Where $\epsilon_x$, $\epsilon_y$, $\epsilon_z$ are normal strains in x, y, z directions

$\sigma_x$, $\sigma_y$, $\sigma_z$ are normal stresses in x, y, z directions

E is Young's modulus

$\nu$ is Poisson's ratio

k is the coefficient of thermal expansion.

The problem must first be solved in terms of displacement rather than by strains or stresses. The first order equations for displacement-strain relationship are[4]

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[4] *Ibid.*, p. 87.

$$\epsilon_x = \frac{\partial u}{\partial x}; \quad \epsilon_y = \frac{\partial v}{\partial y}; \quad \epsilon_z = \frac{\partial w}{\partial z}$$

$$\gamma_{xy} = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}, \quad \gamma_{xz} = \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}, \quad \gamma_{yx} = \frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}$$

where u, v and w are linear displacements in x, y, and z directions respectively.

It is now possible to write the stresses and the equilibrium equations in terms of displacements.

$$\sigma_x = \frac{E}{(1-2\nu)(1+\nu)} \left[ (1-\nu) \frac{\partial u}{\partial x} + \nu \left(\frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)\right] - \frac{EkT}{(1-2\nu)}$$

$$\sigma_y = \frac{E}{(1-2\nu)(1+\nu)} \left[ (1-\nu) \frac{\partial v}{\partial y} + \nu \left(\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z}\right)\right] - \frac{EkT}{(1-2\nu)}$$

$$\sigma_z = \frac{E}{(1-2\nu)(1+\nu)} \left[ (1-\nu) \frac{\partial w}{\partial z} + \nu \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)\right] - \frac{EkT}{(1-2\nu)}$$

$$\tau_{xy} = \frac{E}{2(1+\nu)} \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)$$

$$\tau_{xz} = \frac{E}{2(1+\nu)} \left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\right)$$

$$\tau_{yz} = \frac{E}{2(1+\nu)} \left(\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right)$$

The equilibrium equations become

$$\frac{2(1-\nu)}{(1-2\nu)} \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial x \partial y} + \frac{\partial^2 u}{\partial x \partial z} + \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 w}{\partial x^2} + \frac{2\nu}{1-2\nu} \left(\frac{\partial^2 v}{\partial x \partial y} + \frac{\partial^2 w}{\partial x \partial z}\right) = 0$$

$$\frac{2(1-\nu)}{(1-2\nu)} \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial x \partial y} + \frac{\partial^2 v}{\partial y \partial z} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 w}{\partial y^2} + \frac{2\nu}{(1-2\nu)} \left(\frac{\partial^2 u}{\partial x \partial y} + \frac{\partial^2 w}{\partial y \partial z}\right) = 0$$

$$\frac{2(1-\nu)}{(1-2\nu)} \frac{\partial^2 w}{\partial z^2} + \frac{\partial^2 w}{\partial x \partial z} + \frac{\partial^2 w}{\partial y \partial z} + \frac{\partial^2 u}{\partial z^2} + \frac{\partial^2 v}{\partial z^2} + \frac{2\nu}{(1-2\nu)} \left(\frac{\partial^2 u}{\partial x \partial y} + \frac{\partial^2 v}{\partial y \partial z}\right) = 0$$

The analogous stress equations in cylindrical coordinates are given below where axial symmetry has been assumed. That is, all deviations in the theta direction are zero and v is zero.

$$\sigma_r = \frac{E}{(1+\nu)(1-2\nu)} [ (1-\nu) \frac{\partial u}{\partial r} + \nu (\frac{u}{r} + \frac{\partial w}{\partial z})] - \frac{EkT}{(1-2\nu)}$$

$$\sigma_\theta = \frac{E}{(1+\nu)(1-2\nu)} [ (1-\nu)\frac{u}{r} + \nu (\frac{\partial u}{\partial r} + \frac{\partial w}{\partial z})] - \frac{EkT}{(1-2\nu)}$$

$$\sigma_z = \frac{E}{(1+\nu)(1-2\nu)} [ (1-\nu)\frac{\partial w}{\partial z} + \nu (\frac{u}{r} + \frac{\partial u}{\partial r})] - \frac{EkT}{(1-2\nu)}$$

$$\tau_{rz} = \frac{E}{2(1+\nu)} \quad (\frac{\partial w}{\partial r} + \frac{\partial u}{\partial z})$$

$$\tau_{r\theta} = \tau_{z\theta} = 0$$

The quantities u and w in this case are displacements in the r and z directions respectively while $\theta$, r and z are the cylindrical coordinates.

The equilibrium equations in cylindrical coordinates are:

$$\frac{2(1-\nu)}{(1-2\nu)} [\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r} - \frac{u}{r^2}] + \frac{1}{(1-2\nu)} \frac{\partial^2 w}{\partial r \partial z} + \frac{\partial^2 u}{\partial z^2} = 0$$

$$\frac{2(1-\nu)}{(1-2\nu)} \frac{\partial^2 w}{\partial z^2} + \frac{1}{(1-2\nu)} [\frac{1}{r}\frac{\partial u}{\partial z} + \frac{\partial^2 u}{\partial r \partial z} ] + \frac{1}{r}\frac{\partial w}{\partial r} + \frac{\partial^2 w}{\partial r^2} = 0$$

These, then are the equations which must be solved and are currently being programmed for machine solution.

## 3.0 CONCLUSIONS

The aluminum-germanium solder alloy appears capable of providing an excellent bond between silicon and aluminum. However, to make this system useful, techniques must be developed to prevent interference by aluminum oxide and silicon oxide. Methods are discussed for accomplishing this and will be evaluated during the next report period.

Gold-silicon and gold-germanium eutectic alloys have been ordered for a determination of their thermal conductivities and mechanical properties.

A method has been developed for flattening and holding to close tolerance the degree of parallelism of the large flat surfaces of silicon wafers. This is necessary to provide uniform heat paths through the silicon and will reduce mechanical stress which may arise due to surface roughness.

A thermal conductometer which has been on order for some time has finally arrived and awaits connection to plumbing in the laboratory. This, coupled with an Instron testing instrument and a dilatometer, will provide the basic information required to select materials and geometries best suited for bonding large area silicon crystals to heat sinks.

The basic equations for determining the thermal conductivity and therefore temperature rises in layered elements with discrete power dissipating regions are developed to provide an improved understanding of the assumptions made and the terms involved.

The basic equations for stress analysis are also developed. These are currently being programmed for machine solution.

## 4.0 NEW TECHNOLOGY

No reportable items of new technology have been developed under this contract.